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by

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The Effects of Dune Buggy Sounds on the Telencephalic Auditory Evoked Response in the Mojave Fringe-Toed Lizard, *Uma scoparia*

by

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Abstract

Eight *Uma scoparia* were surgically implanted in their telencephalic auditory regions with active silver electrodes in order to monitor their auditory evoked response to stimuli of known intensities before and after exposure to dune buggy sounds (95 dBA, 100 dBL). Averaged evoked responses (AER),determined by computer-averaging their telencephalic electroencephalogram (EEG), were compared to determine effects of sound exposure. Decreased amplitudes and increased latencies of AER resulted after sound exposure. These data are interpreted as denoting actual hearing loss in the test animals. The importance of the hearing sensation to desert prey animals, relative vulnerability of their hearing apparatus, and critical reproductive cycles of populations of *Uma* within California are discussed with reference to the ecological significance of these findings.

Introduction

The invasion of the Southern California deserts by off-road vehicles (ORV's) has resulted in the spread of high-intensity sounds into formerly quiet, remote arid regions. Individual ORV's with sound intensities as high as 110 dBL have been monitored at several desert locations. Massed ORV activities generating high-intensity sounds have been recorded for durations in excess of five minutes. ORV sounds have been found to permeate deep into the desert and raise the ambient sound levels at distances exceeding 1 km (Bondello and Brattstrom, 1978).

Animals exposed to high-intensity sounds have suffered both anatomical and physiological damage. These effects include both auditory and non-auditory damage. Most noise research, however, has been conducted on animals from non-desert habitats (USEPA, 1971) and only recently have the effects of ORV sounds been investigated (Bondello, MS, 1976).

High-intensity sounds of massed off-road motorcycles were shown to severely damage the acoustical sensitivity of the Desert Iguana, _Dipsosaurus dorsalis_. Exposures of 115 dBA for durations of one and ten hours both resulted in decreased cochlear responses to acoustic stimuli (Bondello, MS, 1976). The _Dipsosaurus_ study demonstrated that high-intensity ORV sounds can damage the peripheral auditory system of desert lizards. "Hearing", as measured by the changes in the electrical activity of the central nervous system (CNS) in response to acoustical stimuli, was not monitored in the Desert Iguanas.

Transient changes in the electrical activity of the CNS in response to sound have long been observed in the electroencephalogram (EEG) of human and non-human vertebrates. The background EEG is often of greater magnitude than those transient changes elicited by acoustic stimuli. The observation of these smaller transient changes in EEG has been greatly facilitated by the use of computer averaging techniques, which electronically add the EEG signals. This technique allows the presumably random, larger background electrical activity to factor itself out through successive additions, while the smaller, non-random, time-locked responses, elicited by the acoustical stimuli, grow into recognizable patterns (Goldstein, 1973). These average evoked responses (AER) have been used for years as clinical criteria in the evaluation of hearing for both human and non-human subjects (Davis, 1976). The measurement of AER's of non-human subjects traditionally involves the placement of intracranial electrodes, in contrast to the extracranial placements normally made on human subjects (Keidel, 1976).

AER's have been monitored from a number of non-human vertebrates including; dogs, cats, rabbits, guinea pigs (Chaloupka, 1966), monkeys (Clopton, 1973), rats (Clopton and Winefield, 1974), bats (Suga, 1964; Grinell, 1970; Andreeva, 1976), porpoises (Bullock and Ridgway, 1972), sea lions (Bullock, Ridgway, and Suga, 1971), dove (Viederman-Thorson, 1967), snakes (Hartline, 1971), lizards (Campbell, 1969), and bullfrogs (Frishkopf and Capranica, 1966). Thus, AER's have been successfully used to determine hearing thresholds in mammalian, avian, reptilian, and amphibian subjects for over a decade.

AER's have been determined for several species of lizards native to the California deserts including; the Desert Banded Gecko, _Coleonyx variegatus variegatus_ (Gekkonidae), the Western Whiptail Lizard, _Cnemidophorus tigris_ (Teiidae), the Yellow-Backed Spiny Lizard, _Sceloporus magister uniformis_ (Iguanidae), the Desert Iguana, _Dipsosaurus dorsalis_ (Iguanidae), the Coachella Valley Fringe-Toed Lizard, _Uma inornata_ (Iguanidae), and the Mojave Fringe-Toed Lizard, _Uma scoparia_ (Iguanidae). Poor AER's were obtained from _Dipsosaur_ _dorsalis_ and _Uma scoparia_, thus, these lizards were considered incapable of hearing low intensity sounds (Campbell, 1969). More recent experiments by

Werner (1972) have contradicted Campbell's results and have shown both Dipsosaurus dorsalis and Uma scoparia to be quite sensitive to low intensity sounds as determined by cochlear response. Campbell's inability to obtain proper AER's probably resulted because the lizards were tested during a season when their hearing responses were at a naturally-occurring low ebb. Seasonality of hearing sensitivity has been observed in other lizards. Inner ear responses of the Australian Stumpy-Tailed Skink, Tachysaurus rugosus, were seen to fluctuate with the season, and were ten times higher during the Spring than the Fall season of Australia (Johnstone and Johnstone, 1969).

The purpose of this study was to determine the hearing thresholds of the Mojave Fringe-Toed Lizard, Uma scoparia using the AER technique. The AER's were to be recorded during the appropriate Summer season to insure a proper intensity of response. Following the recording of a control AER, an individual lizard was to be removed and subjected to a moderate duration (8 minutes and 30 seconds) of dune buggy sounds of intermediate intensity (95 dBA). Following the sound exposure, the AER of the lizard would again be recorded, to allow comparison with the control response. In this way, the actual effect of the dune buggy sound on the individual lizard's hearing threshold could be determined.

These dune buggy sounds represent lower intensities and shorter durations than the maximum reported field values, and have been used to make the study more relevant to exposures more likely to be received by lizards in the field. Uma scoparia was selected because the species range is restricted to aolian sand dune areas only, thus making it a likely recipient of dune buggy sounds as they occur in the field. Because of their limited species range, successful emigration to quieter neighboring habitats by Uma scoparia is not possible.. The lizards used in this study were obtained in an undisturbed dune area five kilometers south of Rice, California.

Materials and Methods

Twenty Uma scoparia were captured by noosing, 5 km south of Rice, Riverside County, California, on 9 July 1978. Lizards were placed into an acoustically-insulated plastic container with internal dimensions of 66 cm x 30 cm x 30 cm. Subjects were immediately transported to California State University, Fullerton, Orange County, California. Animals were randomly separated into two separate acoustically-insulated plastic containers with internal dimensions as above. The insulated boxes could reduce a 100 dBA external noise by 35 dBA. Ten lizards were stored in each box on a substrate of sand taken from their home dunes. An electric timer, connected to a ten-watt light bulb placed on the sandy surface of each container maintained a 12 hour light, 12 hour dark cycle. A Yellow Springs Instrument Company Model 44TD Telethermometer with four thermister probes monitored the internal temerpature of each container. Temperatures within the boxes ranged from 22°C in darkness to 39°C in light. Temperature decreased with distance from the light bulb, which established a thermal gradient in each container. A Schultheiss Quick-Recording Thermometer was used to periodically check the cloacal temperatures of individual lizards. These checks showed the lizards to maintain their temperatures near the preferred 35.7°C reported by Brattstrom (1965). Lizards were maintained on a daily diet of Tenebrio larvae and water. Compartments were cleaned daily.

Lizards were anaesthetized with Sodium pentobarbital (Abbott Labs) injected intraperitoneally at a dosage of 30-40 mg/kg body weight. The subjects were ready for surgery within 25 minutes of injection.

Eight animals were used, seven for testing and one for mapping the electrical responses of the brain. Anaesthetized lizards were secured, dorsum up, in a stereotaxic device, placed inside a grounded copper Faraday cage, located within an acoustically-insulated room. The head was tightly secured, with care taken to avoid crushing the delicate skull. Surgery was performed to remove the parietal, postorbital and nasal scales. Two 1/32 inch holes were drilled in the skull using a dental drill. The first hole, in the nasal bone, was filled with a #80 stainless steel machine screw, 1/16 inch in length. A silver wire, wrapped on this screw, served as an indifferent recording electrode. The second hole, in the parietal bone, 2 mm caudal to the parietal eye and 0.5 mm to the right of midline, allowed passage of the active recording electrode. This electrode was made of 30 guage silver wire covered by glass drawn to within 1 mm of its tip. Careful inspection of each electrode for cracks and breaks was made. Finally, a silver wire ground was passed through the base of the tail. The electrodes were routed, via silver wire in copper coaxial cable, to a Grass Model 7 Polygraph, equipped with a J3b preamplifier and 7 DAF driver amplifier. Output from the driver amplifier (jack J6) was recorded on a Vetter frequency modulated magnetic tape system onto BASF tape at a speed of 7½.

The active electrode was slowly lowered into the lizard's telencephalon while the EEG of the animal was closely monitored on a Tektronix Model 5113 Dual Beam Storage Oscilloscope. A click stimulus with a rise time of less than 2 μsec and fall time of 5 μsec was presented using a Grass Model SD9 stimulator wired directly to a small hearing aid-type earphone placed against the tympanic membrane of the right ear. A series of 100 msec pulses were delivered at a rate of 10 pulses/sec. A 10 msec prepulse output from the SD9 was used to trigger the oscilloscope. The pulse was viewed on a separate channel of the oscilloscope. Both prepulse and pulse were recorded on the Vetter tape system. The active electrode was then lowered further until the characteristic "N-shaped" evoked response was observed on the oscilloscope.

The active electrode was then cemented into place using dental cement and allowed to dry. The experimenter was thus able to view the instantaneous time-locked response on the oscilloscope, with the potential for later analysis of the magnetic tape. A Computer of Average Transients (CAT 400B) was used to average 500 responses for each subject at stimulus intensities, read from the SD9, of 0.1 V (76 dBL), 0.2 V (80 dBL), 1.0 V (83 dBL), and 2.0 V (85 dBL). A total of three recordings of each stimulus intensity were made for each animal, two prior to and one directly after, exposure to dune buggy sounds. After the tape had been checked for play-back quality, the CAT 400B record was transcribed onto paper via a Beckman 10" Chart Recorder run at a chart speed of 5 inches/min and a pen deflection of 22.2 cm/20 uV. The first negative peak of the response (1N) was then measured from the chart record to determine the magnitude of the AER before and after sound exposure.

Lizards were maintained at a body temperature of 38°C ± 1°C during each test run by covering them with a warm water jacket. Head temperatures varied from cloacal temperatures by less than 1.8°C as determined by thermister placement. These temperatures are similar to those reported by Werner (1972) in obtaining smooth acoustical sensitivity functions from Uma scoparia.

Preliminary experiments were conducted from 12 July to 10 August 1978. The actual measurement of AER for the seven test lizards occurred on 11 August 1978. A lizard was surgically implanted and soon after, the first series of stimuli was presented. After this test, the lizard was disconnected from the stereotaxic apparatus and removed, with electrode still implanted, to a quiet room for a period of 30 to 90 minutes. The lizard was then reinserted into the apparatus and the electrode reconnected. A second run was then made to determine any effect due to the process of disconnection and removal from the apparatus. After the second run, the lizard was again disconnected and removed to an insulated chamber. Here the lizard was exposed to a total of 500 seconds of taped dune buggy sounds (95 dBA, 100 dBL). The subject was then reconnected to the apparatus and immediately tested for the third time. Thus, a total of 21 runs were made (three runs per lizard), 14 before noise exposure and 7 directly afterwards. After the third run, lizards were removed, sacrificed, and prepared for histological examination.

High intensity sounds of a 1971 Volkswagen "Baja Bug" were recorded onto a TDK Endless 30-second loop tape, using a battery-powered Panasonic Autostop Cassette Recorder with condenser microphone. A simultaneous recording was made using a Uher 4000C portable tape reocrder, for later sonagraph analysis. The duration of the dune buggy sound was 25 seconds for every 30 second loop of the tape. Thus, for the 30 second loop tape, the sounds were "on" for 25 seconds and "off" for 5 seconds. The noise exposure then, was interrupted and not continuous. Twenty revolutions of the tape were played which resulted in a total sound exposure of 500 seconds (8 minutes and 30 seconds). A Kay Electric Company Sound Spectrograph set on "normal" analyzed the relative intensity distribution of the sounds over the frequency spectrum. A Bruel and Kjaer Precision Sound Level Meter Type 2203 with 1613 Octave Band Filter Set monitored the overall intensity of the dune buggy sounds.

The dune buggy sounds were played to the lizards from the loop tape, via the cassette recorder, to a McIntosh Model MI-75 Power Amplifier which amplified the signal through to an Electro-Voice sP8B 8-inch Coaxial Loudspeaker. Signal intensity was increased until 95 dBA (100 dBL) was reached 8 cm in front of the speaker. This intensity is lower than the maximum (105 dBL) value actually recorded from dune buggies in the field (Bondello and Brattstrom, 1978).

Results

The intensities of the 1971 Volkswagen "Baja Bug" recorded in this study exceeded 95 dBA (100 dBL) at 5 meters. Sonograph analysis (Figure 1) revealed major energies concentrated below 1000 Hz with minor energies extending to 2500 Hz and residual energies up to 8000 Hz.

The typical response to a 0.1 msec pulse of 0.1 V (76 dBL) is given for the first control run of lizard #20 (Figure 2). The response is characterized by alternating negative (upward) and positive (downward) deflections. The first negative (1N) peak occurs at 1.5 msec after the termination of the stimulus. This 1N peak is followed by the first positive (1P) peak at 2.5 msec, the second negative (2N) peak at 3.5 msec, and the second positive (2P) peak at 5.5 msec after the stimulus. The waveform then steadily rose to regain the normal baseline EEG pattern until the next stimulus was presented.

The amplitude of the control 1N peak varied with the stimulus intensity (Table 1). Control 1N peak amplitudes ranged from 0.9-3.1 uV ($\overline{X}$ = 1.67) for stimulus intensities of 0.1 V (76 dBL), 1.1-5.3 uV ($\overline{X}$ = 2.63) at 0.2 V (80 dBL), 1.8-9.8 uV ($\overline{X}$ = 5.59) at 1.0 V (83 dBL), and 1.8-10.5 uV ($\overline{X}$ = 5.70) at 2.0 V (85 dBL). Increased stimulus intensities, then, tended to increase the amplitude of the 1N in the control runs up to intensities of 2.0 V (85 dBL) (Figure 3).

Preliminary tests performed on the lizard used to electrophysiologically "map" the AER revealed that the amplitude of the 1N peak did not vary as a linear function of intensity (Figure 4). The magnitude of the 1N AER of the "map" lizard rose to a maximum at 1.0 V (83 dBL) and steadily fell to lower values with increased stimulus intensities of 2.0 V (85 dBL), 4.0 V (86 dBL), and 6.0 V (87 dBL). This non-linear function after the maximum 1N peak is consistent with the findings of Werner (1972) and probably represents the point at which the increased acoustical input overloads the ability of the sensitive lizard ear to respond.

The latencies of the 1N peak following stimulation also varied with stimulus intensity (Table II). The 1N peaks of the first control run were 1.5-1.9 msec ($\overline{X}$ = 1.55) at stimulus intensities of 0.1 V (76 dBL), 1.0-1.5 msec ($\overline{X}$ = 1.38) at 0.2 V (80 dBL), 1.0-1.8 ($\overline{X}$ = 1.21) at 1.0 V (83 dBL), and 1.0-1.5 msec ($\overline{X}$ = 1.07) at 2.0 V (85 dBL). Thus, as the stimulus intensity was increased, the latency of the 1N response decreased (Figure 5). These findings are consistent with AER's obtained from human subjects (Hecox and Galambos, 1974).

The experimental procedures of electrode disconnection and reconnection did not reduce the amplitude nor shift the latency of the 1N response of any experimental subject. Comparison of the first and second control runs indicate that the careful manipulation of electrodes and animals did not contribute to any alteration of the characteristic amplitude and latency of the 1N response of _Uma scoparia_.

AER's of _Uma scoparia_ significantly varied (Table III) after exposure to dune buggy sounds (Figure 6). Comparison of first control runs with exposed (after sound treatment) runs showed the amplitude of the mean 1N responses to decrease (Table I a and b) and latencies to increase (Table II a and b) after exposure to dune buggy sounds. Decreased amplitudes and increased latencies of neural responses to standard auditory stimuli are diagnostic symptoms of hearing loss as described by Aran (1971). The decreased amplitudes (Figure 3) and increased latencies (Figure 5) caused by the dune buggy sounds are, therefore, interpreted as representing actual hearing losses in the exposed lizards. Seven _Uma scoparia_, therefore, suffered actual hearing loss after being exposed to 500 seconds of 95 dBA (100 dBL) dune buggy sounds.

Table I Amplitude of the first negative (1N) average evoked response (AER) in microvolts of the Control and Exposed runs for 7 *Uma scoparia* at four stimulus intensities of 0.1 V (76 dBL), 0.2 V (80 dBL), 1.0 V (83 dBL), and 2.0 V (85 dBL). 500 responses were averaged for each intensity.

	Averaged Evoked Response (microvolts)							
	a. Control				b. Exposed			
Lizard #	0.1V	0.2V	1.0V	2.0V	0.1V	0.2V	1.0V	2.0V
4	1.2	1.3	9.8	10.5	0.6	0.6	0.9	0.6
5	3.1	5.3	7.6	7.6	2.3	4.2	4.4	6.5
6	1.8	1.8	2.7	2.3	1.5	1.5	2.7	2.0
15	1.3	1.6	3.7	5.8	1.2	2.6	4.4	4.0
17	1.0	2.9	7.7	6.4	1.0	1.4	0.6	1.7
18	0.9	1.1	1.8	1.8	0.9	0.6	0.7	0.8
20	2.4	4.4	5.8	5.5	0.6	0.4	1.3	1.8
$\bar{x}$	1.67	2.63	5.59	5.70	1.16	1.61	2.14	2.49

Table II Latency of the first negative (1N) average evoked response (AER) in milliseconds (msec) of the Control and Exposed runs for 7 *Uma scoparia* at four stimulus intensities of 0.1V (76 dBL), 0.2 V (80 dBL), 1.0 V (83 dBL), and 2.0 V (85 dBL). 500 responses were averaged for each intensity.

	Latency (milliseconds)							
	a. Control				b. Exposed			
Lizard #	0.1V	0.2V	1.0V	2.0V	0.1V	0.2V	1.0V	2.0V
4	1.5	1.2	1.0	1.0	1.5	1.5	1.0	1.0
5	1.5	1.3	1.2	1.0	1.5	1.5	1.0	1.0
6	1.5	1.0	1.0	1.0	1.5	1.5	1.5	1.5
15	1.5	1.5	1.5	1.0	1.9	1.5	1.5	1.5
17	1.5	1.5	1.5	1.0	1.5	1.5	1.5	1.5
18	1.9	1.5	1.8	1.5	1.9	1.5	1.5	1.0
20	1.5	1.5	1.0	1.0	1.5	1.5	1.5	1.5
$\bar{x}$	1.55	1.38	1.21	1.07	1.61	1.50	1.35	1.28

Table III Two-way ANOVA with replication for 7 _Uma_ _scoparia_ tested on 11 August 1978.

Source of Variation		df	SS	MS	F_s
	Sub.	7	154.4613	22.066	
A	Exp. Gp.	1	58.6302	58.6302	15.342 ***
B	Treat.	3	72.2877	24.096	6.305 **
Interaction					
	A x B	3	23.5434	7.848	2.054 ns
	Error	48	183.4286	3.821	
	Total	55	337.8899		

F .001 (1.40) = 12.6

F .01 (3.40) = 4.31

ns $P \geq 0.5$

** $P \leq 0.05$

*** $P \leq 0.01$

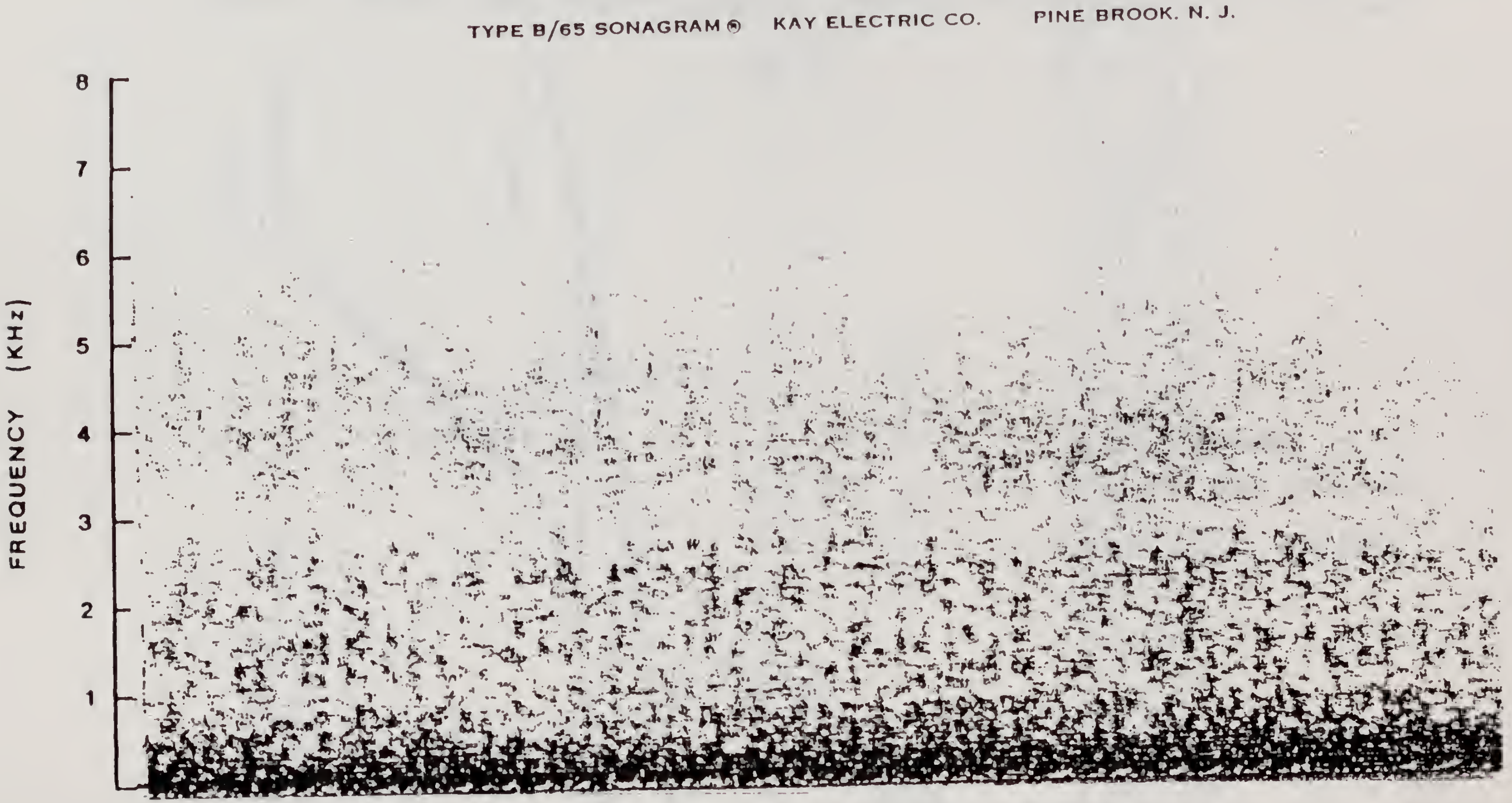

FIGURE 1: SONAGRAM OF 1971 VOLKSWAGEN BAJA BUG AT 5 M.

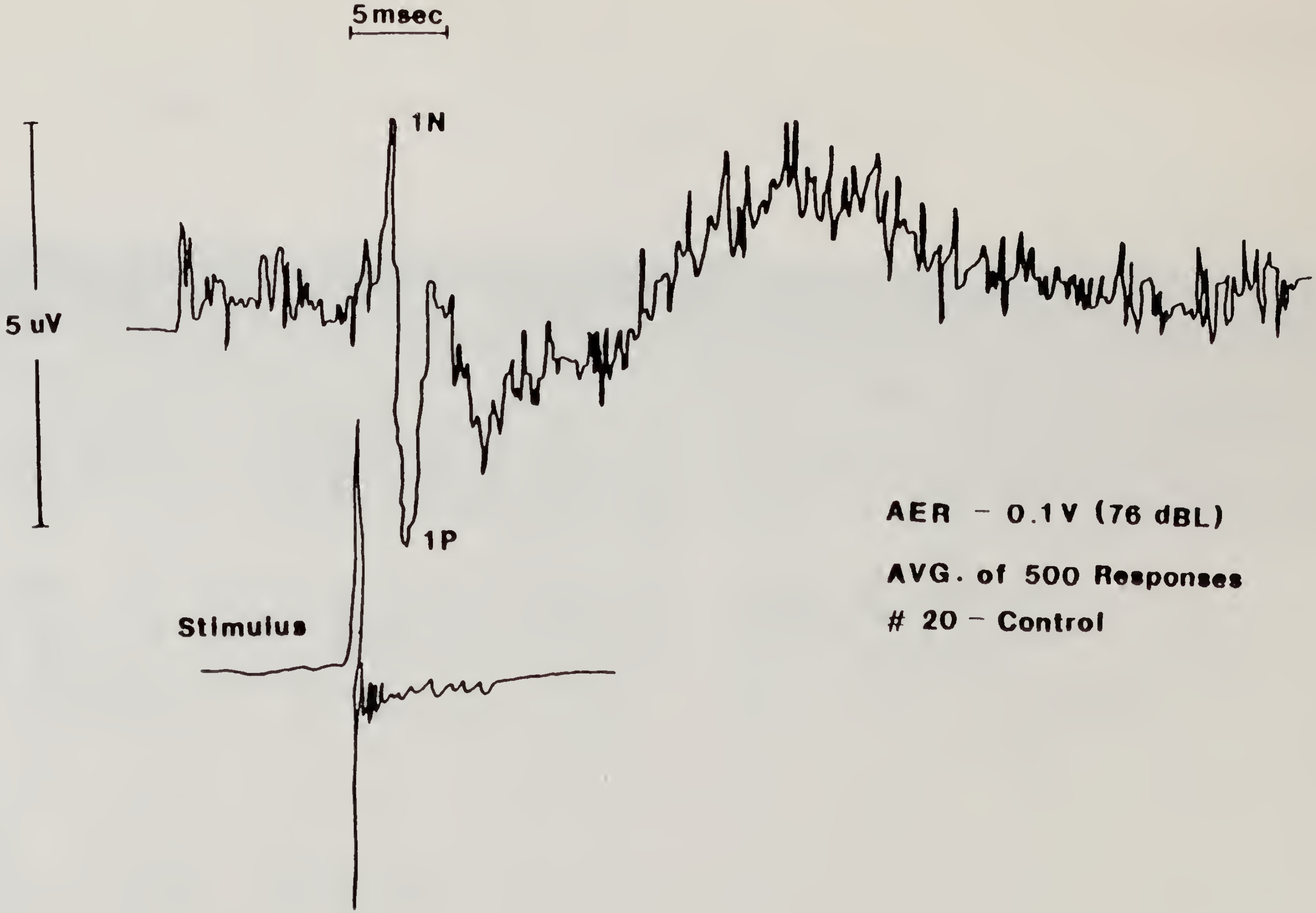

Figure 2: Average evoked response (AER) of lizard #20 to a stimulus of 0.1 V (76 dBL) during a Control run. First negative (1N) response occurs at 1.5 msec after the stimulus, the first positive (1P) response occurs at 2.5 msec. 500 responses were averaged to produce this waveform.

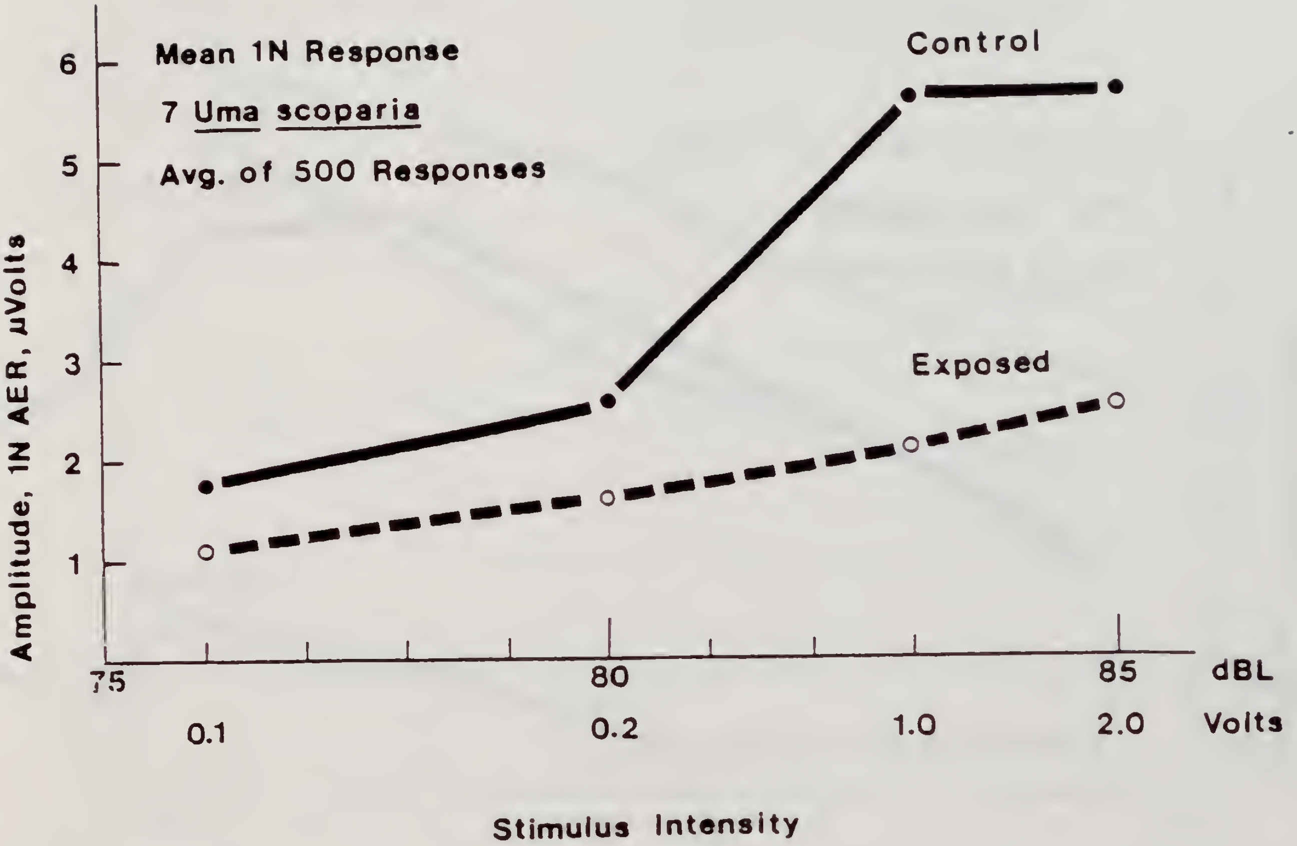

Figure 3: Comparison of the mean amplitude of the first negative (1N) average evoked response (AER) in microvolts (uVolts) for the Control and Exposed runs of 7 *Uma scoparia* at four stimulus intensities of 0.1 V (76 dBL), 0.2 V (80 dBL), 1.0 V (83 dBL), and 2.0 V (85 dBL). 500 responses were averaged for each subject at each intensity. (solid line = Control, dashed line = Exposed).

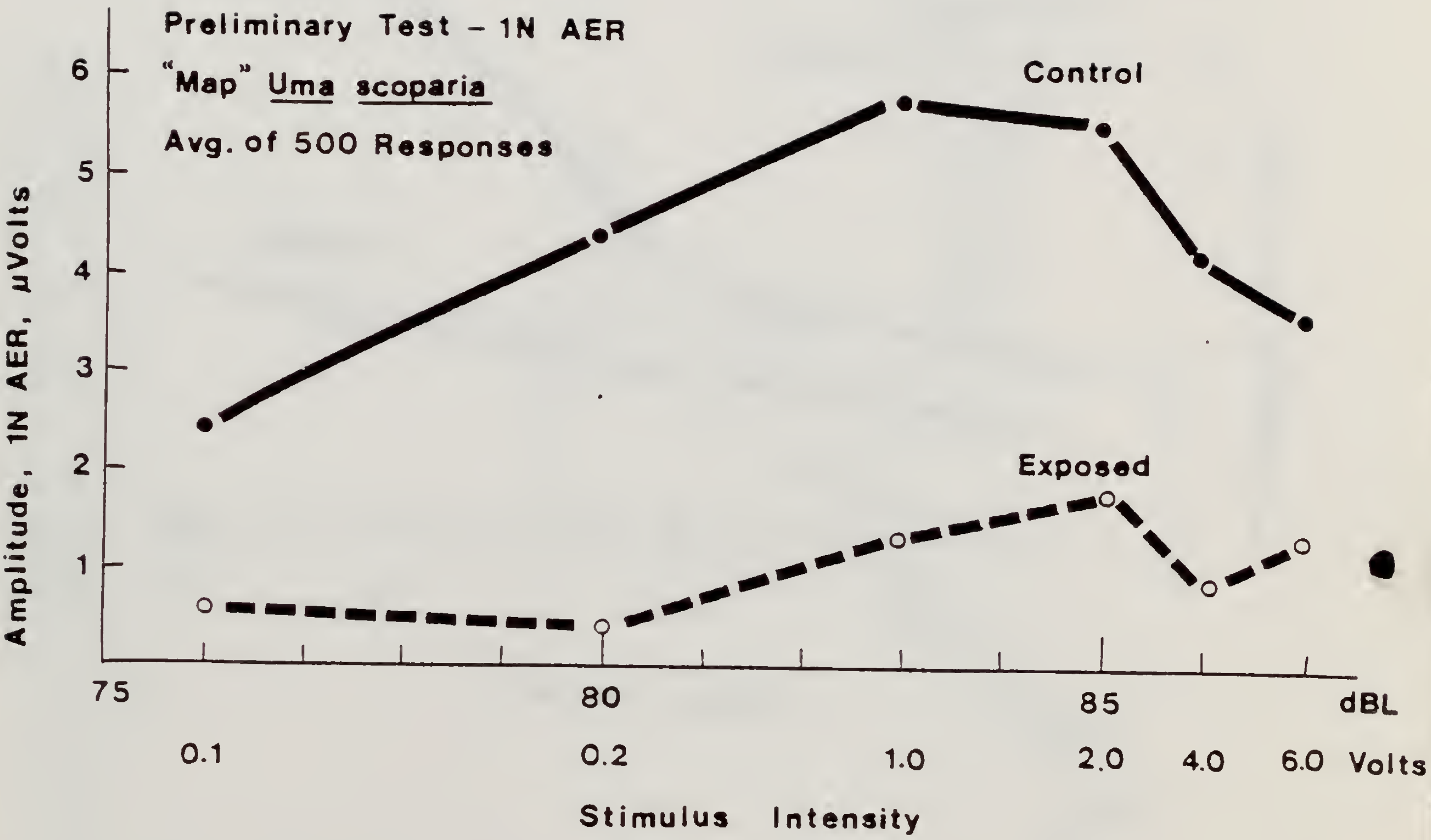

Figure 4: Preliminary test of the lizard used to electrophysiologically "map" the first negative (1N) average evoked response (AER) for Control and Exposed runs at six stimulus intensities of 0.1 V (76 dBL), 0.2 V (80 dBL), 1.0 V (83 dBL), 2.0 V (85 dBL), 4.0 V (86 dBL), and 6.0 V (87 dBL). 500 responses averaged at each intensity. (solid line = Control, dashed line = Exposed).

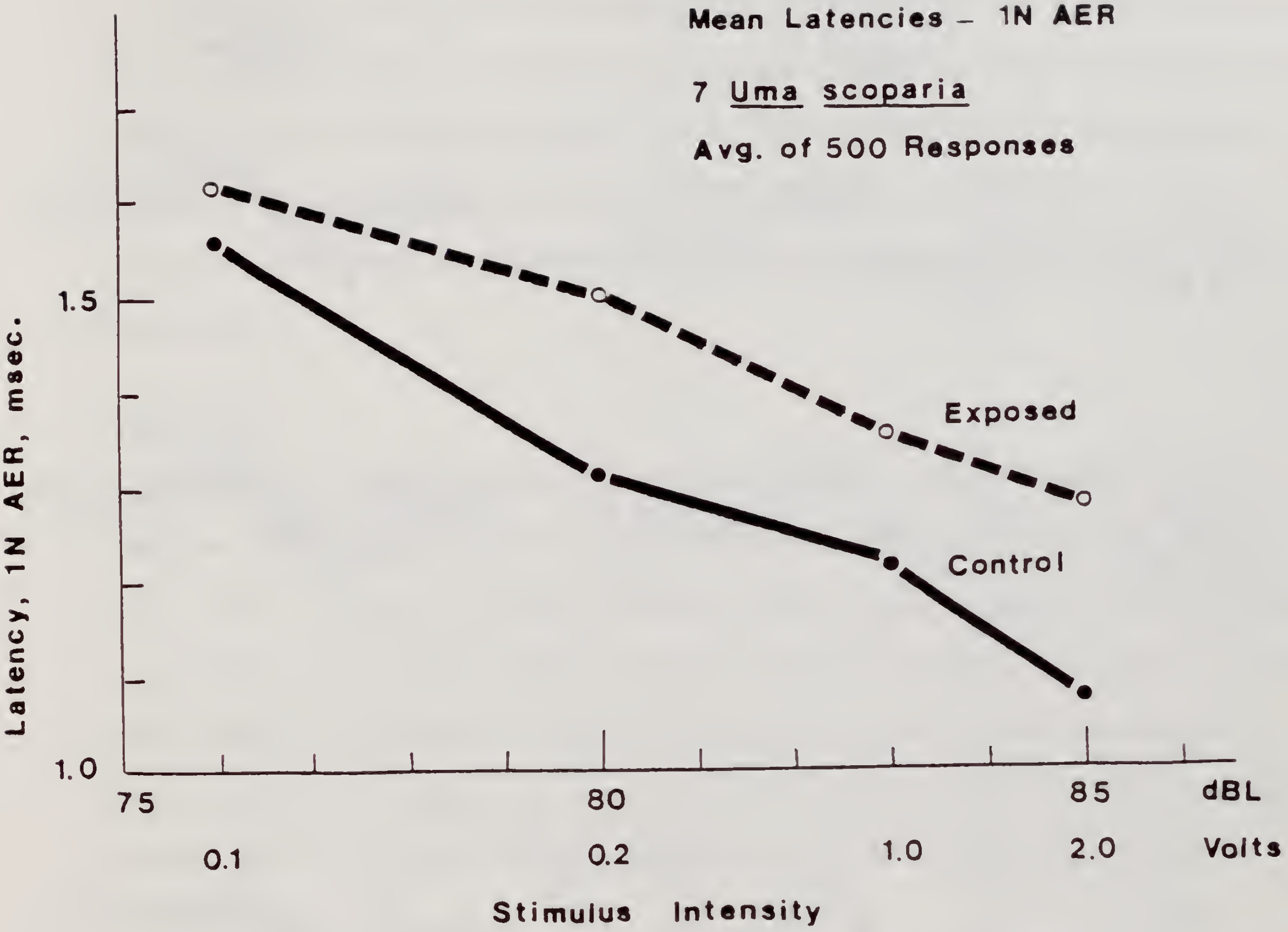

Figure 5: Effects of click intensity on the mean latency in milliseconds (msec) of the first negative (1N) average evoked response (AER) for the Control and Exposed runs of 7 *Uma scoparia* at four intensities of 0.1 v (76 dBL), 0.2VV (80 dBL), 1.0 V (83 dBL), and 2.0 V (85 dBL). 500 responses averaged for each subject at each intensity. (solid line = Control, dashed line = Exposed).

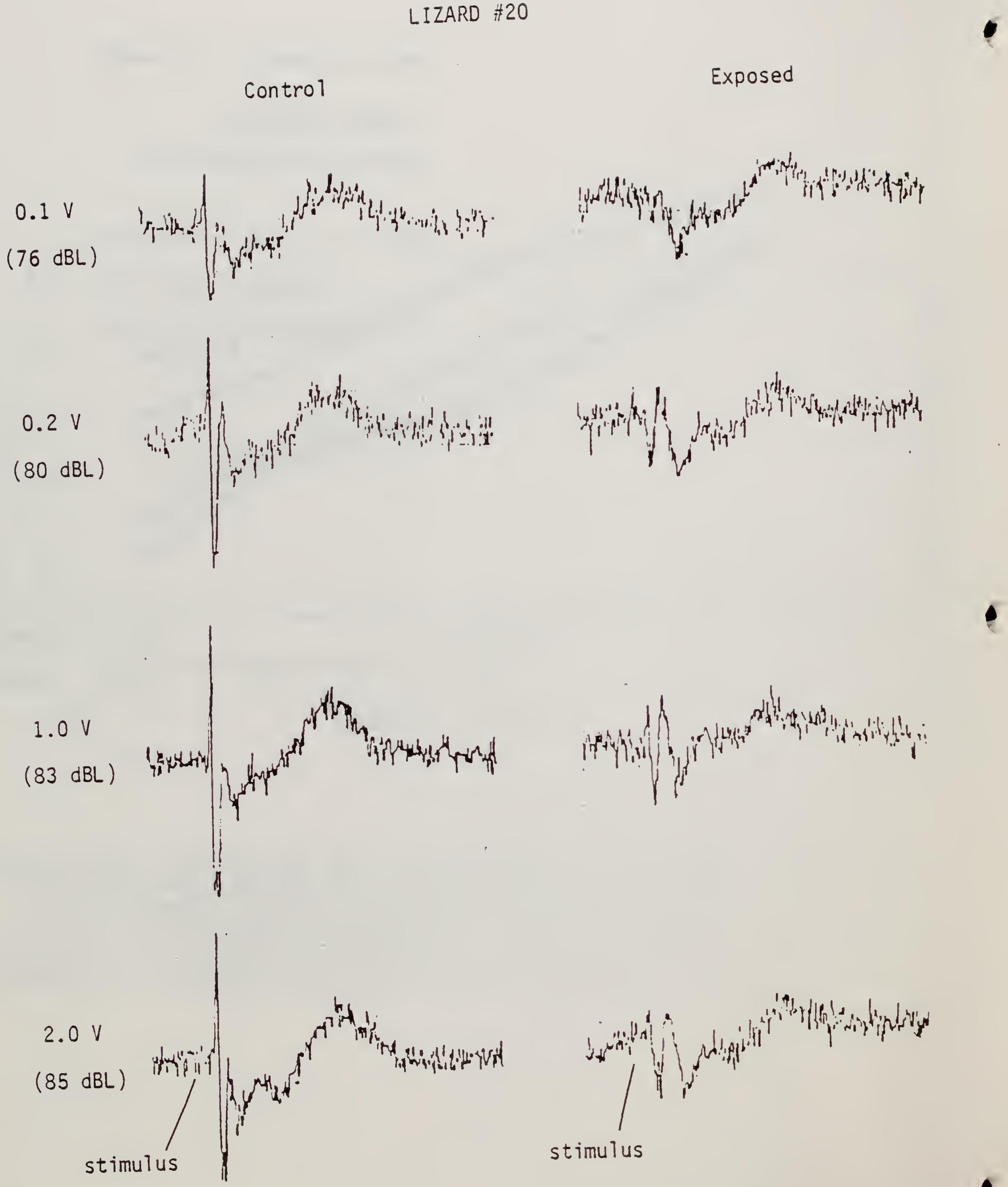

Figure 6: Comparison of the average evoked response (AER) of lizard #20 for Control and Exposed runs at four stimulus intensities of 0.1 V (76 dBL), 0.2 V (80 dBL), 1.0 V (83 dBL), and 2.0 V (85 dBL). Note decline in the amplitude and increase of the latency of each response after exposure to dune buggy sounds. 500 responses were averaged for each intensity.

Histological examination revealed the locations of the electrode implants. These exact locations correspond to the right medial (auditory) zone of the anterior dorsal ventricular ridge of the right telencephalic hemisphere as described for Iguanids by Northcutt (1978). Thus, the electrodes were implanted in the proper neuroanatomical coordinates to record auditory evoked potentials.

Discussion

These data clearly indicate that dune buggy sounds of comparatively moderate intensity and short duration contain sufficient acoustical energies below 3 KHz (Figure 1) to induce hearing loss in *Uma scoparia*, as evidenced by decreased amplitudes (Figure 3) and increased latencies (Figure 5) of the first negative responses of their AER. Mechanized sounds of equivalent or larger acoustical dosage may, therefore, be expected to inflict similar detectable hearing losses on *Uma scoparia* exposed during the spring and summer seasons.

The early electrophysiological responses monitored from the lizard telencephalon are similar to those recorded from the brain stem of human subjects (Hecox and Galambos, 1974). The sequence of negative and positive waves which appear before the first 10 msec after stimulation were originally described by Jewett, Romano, and Williston (1970) as being surprisingly consistent in occurrence with an absence of electrical artifact beyond the first fraction of a millisecond. The reliability of these early responses has been demonstrated as a useful method of assessing hearing in infant and adult human subjects, some of whom were incapable of voluntarily responding to auditory stimuli.(Hecox and Galambos, 1974). The same procedures are, therefore, regarded as an accurate method of evaluating the hearing thresholds of similarly non-communicative lizards.

The earliest AER in human subjects, Jewett and Williston's peak I, appears about 1 msec post-stimulus and presumably results from the first neural volley of the auditory nerve (Hecox and Galambos, 1974). The 1N response of Uma scoparia (1-1.5 msec), then, is assumed to reflect a similar firing of the lizard auditory nerve. The designation "1N" is not meant to imply any relation to the early peak "I" (Jewett et al, 1970) or the later "n_1" responses of previous workers (Davis, 1976). Rather, 1N is used only to designate the first negative waveform of the AER of Uma scoparia described in this study and should not be confused with any other clearly defined nomenclature assigned to other recognized response waves.

A brief explanation is required to place this laboratory study within a framework of ecological relevance. This explanation concerns the nature and occurrence of dune buggy sounds and the activities of the fringe-toed lizards themselves.

The most frequently occurring, high-intensity sounds monitored in the Southern California Desert over an 18-month survey were generated by ORV's. Individual ORV's have been monitored with SPL's as high as 110 dBL (Bondello and Brattstrom, 1978). Formerly remote quiet desert areas are now traversed regularly by ORV's. Massed ORV activities can raise the ambient SPL's for durations of several hours. The most frequently encountered ORV's in the California deserts were motorcycles (Bondello and Brattstrom, 1978), however, most motorcycles are unable to penetrate the interiors of the wide soft sand dune systems characteristic of the Imperial Sand Dunes, Devil's Playground, and the Rice Sand Hills. Dune areas, then, are often spared the intense motorcycle activities, which tend to be concentrated in less difficult terrain (hardpan, sandy washes, and dune peripheries). Sand dune systems, then, represent a greater challenge to ORV enthusiasts due to their relatively more difficult terrain. The result is that four-wheeled vehicle activity (jeeps, sand rails, Baja bugs, etc.) tends to be most intensely concentrated on the sand dunes. Dune buggies are able to penetrate deep into the interior of sand dune systems due to their superior maneuverability and traction on the sandy substrate. Many areas within the dune periphery are, therefore, exposed to repeated episodes of high-intensity sounds. Dune buggies most often maximize engine speeds in order to manueuver over or through soft sand areas. Accelerated engine speeds produce similar elevations of sound pressure levels, thus, high-intensity sounds are often characteristic of dune buggy activities.

Dune buggy sounds with major energies concentrated below 3 KHz (Figure 1) have been monitored with intensities of 105 dBL at ranges of 50 m. Stationary dune buggies have been monitored with engines "revved" at high speed with subsequently high sound pressure levels for durations exceeding 5 minutes (Bondello and Brattstrom, 1978). Many dune buggies have been observed repeatedly traversing the same area of sand dunes within a one hour period. Wide-ranging dune buggies were observed deep within the dune interior, repeatedly crossing the same terrain. Dune buggies, then, may be characterized by high engine speed (high sound pressure level) activities, which often range widely over the dune systems, with repeated passages over selected terrain. When these intensely concentrated dune buggy activities on sand dunes are viewed (especially at ORV playgrounds such as Glamis, California), it becomes quite apparent that the cumulative acoustical dosages delivered at any one spot on the dunes system during an active spring or summer weekend morning are at least as great as those delivered to the lizards in this study. Thus, these high-intensity sounds are a regularly occurring phenomena in the California desert regions during the spring and summer months.

The major energies of dune buggy sounds (Figure 1) coincide with the frequencies of maximum acoustical sensitivity for Uma scoparia, 1000-1600 Hz, as determined by Werner (1972). Uma notata notata, the Colorado Fringe-Toed Lizard, has a similar maximum acoustical sensitivity range, 1000-2000 Hz, and responds to intense acoustical stimulation (Wever and Peterson, 1963) in a pattern not unlike those described for Uma scoparia in this report (Figure 4). Thus, these data suggest that dune buggy sounds are inherently damaging to the hearing sensitivity of Fringe-toed lizards.

Fringe-toed lizards are completely restricted to the fine, loose, wind-blown sand of desert dunes, riverbanks, and washes (Stebbins, 1966). Fringe-toed lizards, then, are unable to successfully leave their sandy habitat, and are incapable of evacuating the habitat most heavily impacted by dune buggies.

When disturbed in the field, Uma scoparia seldom escaped into deep burrows. Of the 20 Uma scoparia captured for this study, not one sought the refuge of nearby rodent burrows. Many hid among surface vegetation or burrowed only a few millimeters below the sand surface, often at the mouth of a rodent burrow. When Uma scoparia were pursued, their quick turn into the mouth of a burrow and rapid shallow burial near the entrance gave the impression of escape into the deep rodent burrow. Repeatedly, however, the lizards were found just beneath the surface near the entrance of the burrow. Similar escape strategies have been described for several species of Uma. Pough (1970) described shallow burial (less than 2 cm deep) or retreat beneath bushes as the escape responses of Uma notata to predators. He also described the tendency for Uma to preferentially locate themselves at sand depths of nor more than 4 cm from the surface. Commins and Savitsky (1973) observed Uma exsul when approached to "sand swim," hide beneath tumble weeds, or lie motionless and cryptically colored on sand surfaces. Carpenter (1967) noted a tendency for Uma exsul to shallowly burrow near rodent burrow entrances.

Uma will seek the refuge of rodent burrows when soil and climatic conditionsare favorable. In damp, compacted soil which receive summer rainfall (Kelso Dunes in 1967) conditions were favorable for the maintenance of rodent burrow systems and Uma scoparia retreated to them rather than bury themselves in sand (Pough, 1970). Carpenter (1967) noted a similar tendency for Uma exsul and Uma paraphygas to preferentially retreat to rodent burrows rather than sand swim. Uma constructed its own burrows in moist sand under laboratory conditions (Pough, 1970).

When soil and climatic conditions are less favorable (less cohesive, dry, windblown sand) fewer rodent burrows are maintained. During such conditions (Palm Springs, Panorama, in 1968) fewer burrows were available as retreats. Because of the territorial behavior of Uma, crowding into burrows would probably not occur (Pough, 1970). Thus, more Uma will be forced to seek refuge outside of burrows during seasons of low burrow availability.

A shallowly buried lizard is more likely to receive a higher intensity sound exposure from a nearby dune buggy than would a deeply burrowed lizard. Our laboratory observations indicate that 4 cm of fine compacted sand from Rice, California, does not noticeably lower the sound pressure level of a 95 dBA sound. Thus, due to restricted species distribution and shallow and surface escape tendencies, fringe-toed lizards are particularly prone to receive damaging, short-duration exposures of recurring dune buggy sounds. These exposures may be most intense during the most active ORV months of the spring and summer season.

Intense ORV activities of the spring and summer months, however, coincide with the reproductive season of all three species of *Uma* which occur in California. *Uma inornata* are reproductively active from March to September (Mayhew, 1965), *Uma notata* from April to September (Mayhew, 1966a), and *Uma scoparia* from April to July (Mayhew, 1966b). All California species of *Uma* apparently reach their peak of reproductive activities in May (Mayhew, 1965, 1966a, 1966b). Thus, during the most critical phase of their life cycle, the breeding season, their habitat is subjected to the most intense degree of ORV impact.

When favorable environmental conditions (proper winter rains and abundant annual plant bloom) do not occur, *Uma's* preferred annually migrating insect prey may be scarce on the dunes. *Uma* are then forced to switch to a less easily obtained insect prey which frequent perennial plants. Their lowered energy intake may delay and subsequently decrease the reproductive success of *Uma* for the entire season. If such conditions (drought) persist for several seasons, population sizes of *Uma* may be reduced (Mayhew, 1966b). Thus, the potential impacts of ORV's on *Uma* are especially high during conditions of drought, wherein populations are reduced in size and fewer rodent burrows are available as retreats. At these times of extreme dryness, and low annual plant bloom, the dune habitat of fringe-toed lizards are most sensitive to ORV impact.

The importance of hearing to *Uma* is probably related to prey acquisition and predator avoidance. Environmental sounds of potential importance; rustling of dry leaves by insects, digging and sniffing of dogs, crawling snakes on loose gravel, striking rattlesnakes, and swooping owls all produce low-intensity sounds which have strong components within the range of 1000-4000 Hz. These potentially important sounds coincide with the maximum acoustical sensitivities (900-3500 Hz) of lizards of the families Iguanidae, Gekkonidae, Anguidae, and Teiidae (Campbell, 1969). The sensitivities of lizards to these specific frequencies certainly implies that a great selective advantage is gained in detecting these subtle environmental sounds.

Good hearing ability is especially important for animals that inhabit quiet natural environments such as the desert where ambient sound pressure levels are often as low as 30 dBL (Bondello and Brattstrom, 1978). The attenuation of sounds due to increased temperature and decreased humidity (Harris, 1967) makes the desert an especially quiet environment. The regions within the perimeter of long, continuous sand dunes such as the Algodones Dunes, the largest in California and habitat of _Uma notata_ (Norris, 1958) are especially quiet due to the establishment of shadow zones of suppressed noise. In these regions, the sand dunes act as a barrier preventing the intrusion of high-intensity ground generated noise similar to acoustical barriers constructed near freeways (Federal Highway Administration, 1976). Due to the rapid attenuation of higher frequency sounds, reception of natural sounds above 1000 Hz implies nearness and often danger to prey animals (Hardy, 1956). Thus, the importance and selective advantage of possessing and maintaining a healthy hearing apparatus capable of detecting subtle sounds within the 900-3500 Hz range for fringe-toed lizards as well as other desert animals is again strongly implied.

The extreme vulnerability of the hearing apparatus of _Uma scoparia_ to short durations of high-intensity sound is not demonstrated in humans. Human noise exposure limits set by the Occupational Safety and Health Administration

(OSHA) prescribe a recommended cumulative exposure to 95 dBA noise not to exceed four hours. Uma scoparia suffered hearing loss with a cumulative exposure of 500 seconds to 95 dBA sounds. Thus, the larger, more sohpisticated, better protected human ear is capable of withstanding high-intensity sound exposures which easily damage the smaller, more simplistic lizard ear. OSHA and EPA recommended noise guidelines established for the protection of human hearing, then, are not necessarily applicable to the protection of wildlife hearing. An acceptable vehicle noise limit in urban areas may, in a relatively short period of time, be capable of severely damaging the hearing of exposed wildlife populations.

Awareness of these pronounced differences between human and desert vertebrate auditory systems, the relative vulnerability to acoustical trauma of desert species, the importance of the detection of subtle low-intensity sounds in the daily lives of wildlife, the significance of the 900-3500 Hz sensitivity range, the relative quiet of remote natural areas, all are fundamental to the specific understanding of the effects of dune buggy sounds on Uma scoparia, and more generally, to the effects of high-intensity mechanized sounds on wildlife. Unless these fundamental aspects are realized and addressed the ecological significance of this report, or any similar investigation concerning the effects of noise on wildlife, will not be recognized.

Recommendations of this report are that dune systems with known populations of fringe-toed lizards be immediately considered as "sensitive" areas, especially during times of drought and subsequent low annual productivity. All unnecessary disturbances (ORV activity, mining, repeated low jet overflights, gunnery) should be immediately restricted from the immediate vicinity of these dune systems. This report does not mean to imply that habitat disturbance of a non-acoustical nature (grazing) should not also be restricted from these areas. Indeed, as sensitive areas, the dune system is especially fragile to a variety of disturbances. We simply state, that considering the acoustical data, alone, the animals of the dune systems, especially those of the interior "shadow zone" are particularly vulnerable to mechanized acoustical intrusion and we, therefore, recommend the restriction of high-intensity sound activities from these areas.

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